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(12) United States Patent
Talaski

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(54) **IMPELLER AND FLUID PUMP**

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(73) Assignee: **TI Group Automotive Systems, L.L.C.**, Auburn Hills, MI (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 807 days.

(21) Appl. No.: **13/360,206**

(22) Filed: **Jan. 27, 2012**

(65) **Prior Publication Data**

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Related U.S. Application Data

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(51) **Int. Cl.**

F04D 5/00	(2006.01)
F04D 29/18	(2006.01)
F04D 29/42	(2006.01)

(52) **U.S. Cl.**

CPC ***F04D 29/188*** (2013.01); ***F04D 5/005*** (2013.01); ***F04D 5/007*** (2013.01); ***F04D 29/4273*** (2013.01); ***F04D 29/4293*** (2013.01); *Y10T 29/49316* (2015.01)

(58) **Field of Classification Search**

CPC F04D 5/005; F04D 5/007; F04D 29/188; F04D 29/4273; F04D 29/4293; F05B 2230/10–2230/104; F05D 2230/18

USPC 415/55.1–55.7

See application file for complete search history.

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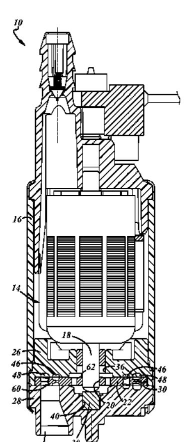
(57) **ABSTRACT**

A fluid pump may include an electric motor having an output shaft driven for rotation about an axis and a pump assembly coupled to the output shaft. The pump assembly has a first cap and a second cap with at least one pumping channel defined between the first and second caps, and an impeller between the first and second caps. The impeller is driven for rotation by the output shaft of the motor and includes a plurality of vanes in communication with the at least one pumping channel. Each vane has a root segment and a tip segment and a line from a base of the root segment to an outer edge of the tip segment trails a line extending from the axis of rotation to the base of the root segment by an angle of between 0° and 30° relative to the direction of rotation of the impeller.

29 Claims, 8 Drawing Sheets



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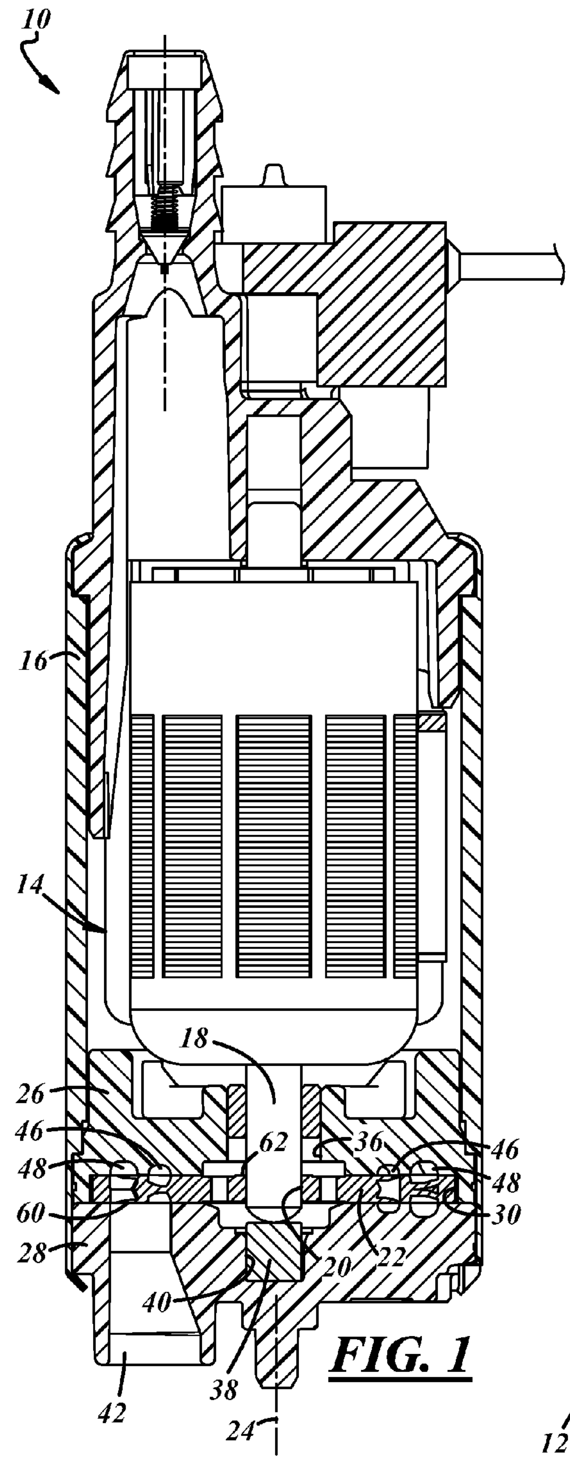

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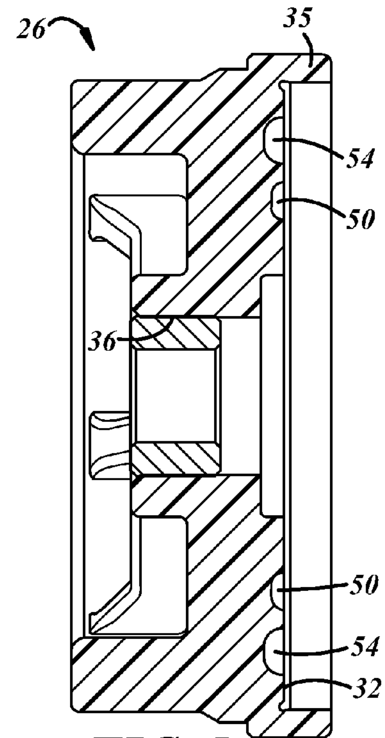

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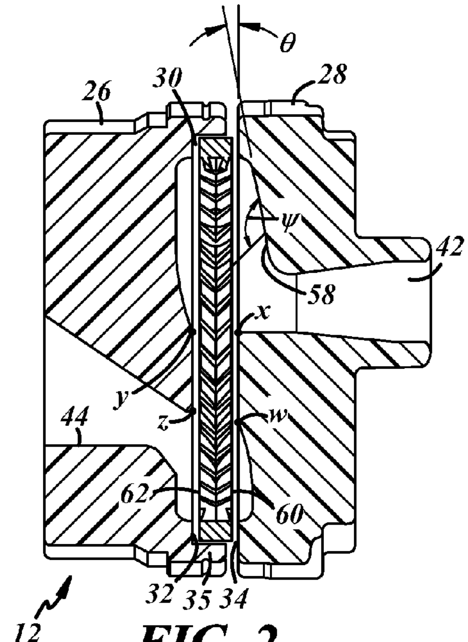

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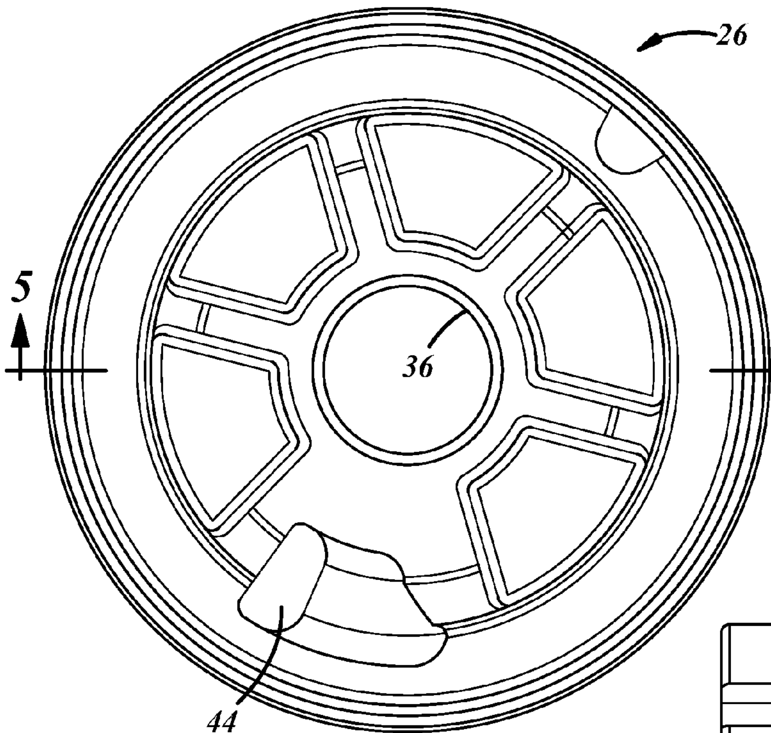

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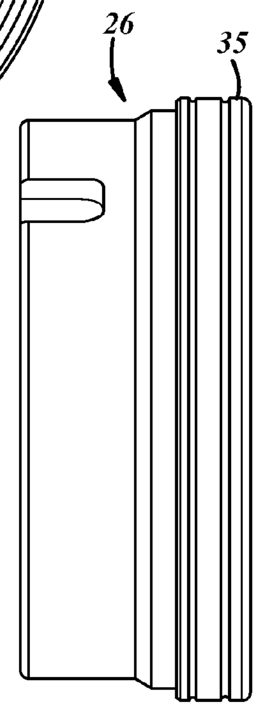

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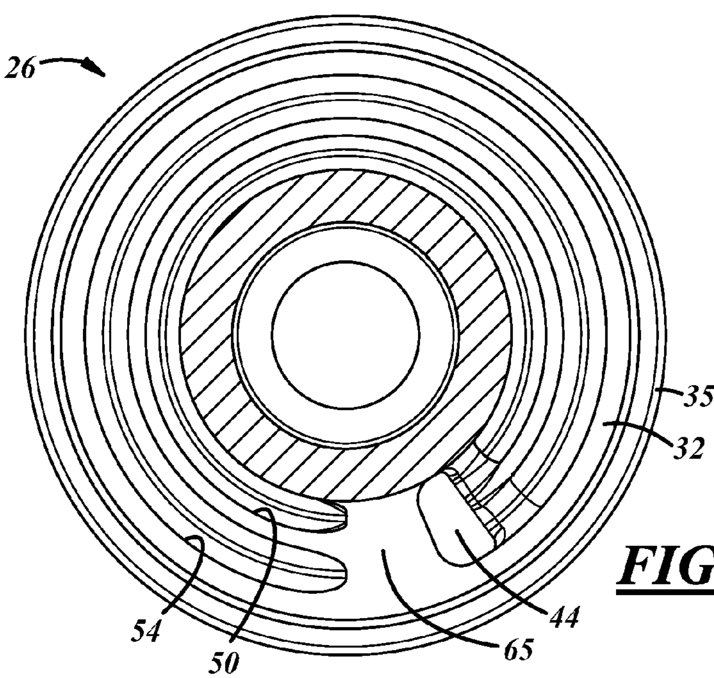

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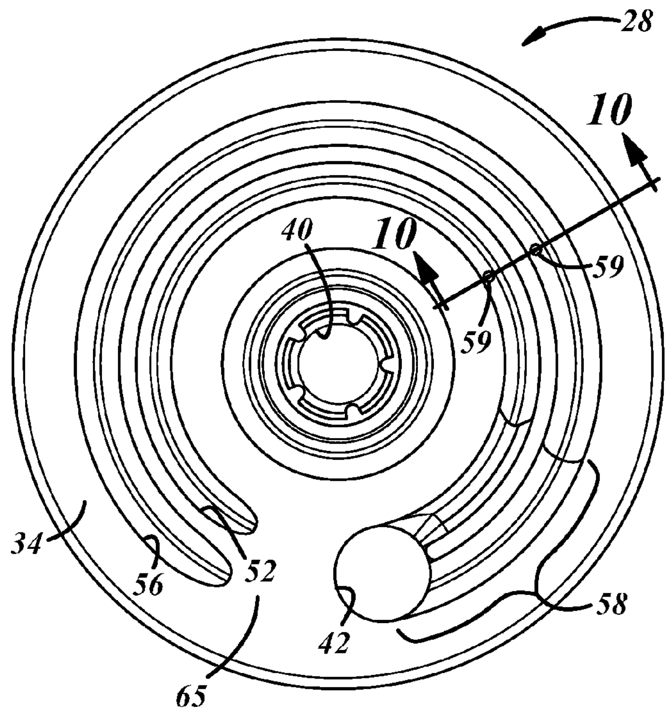

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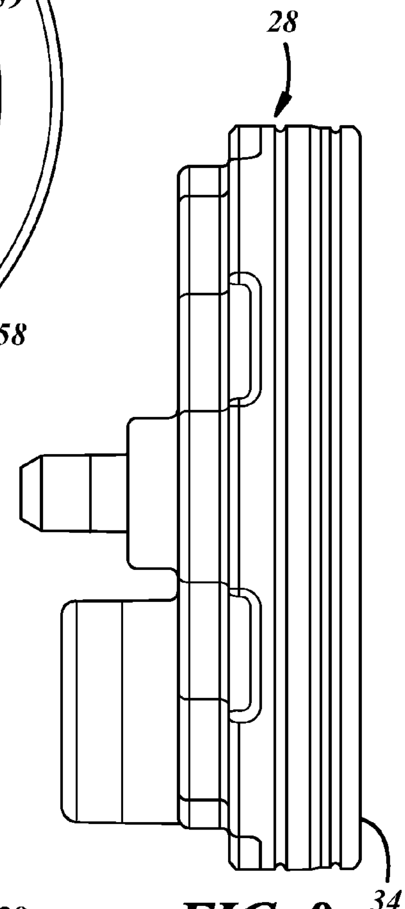

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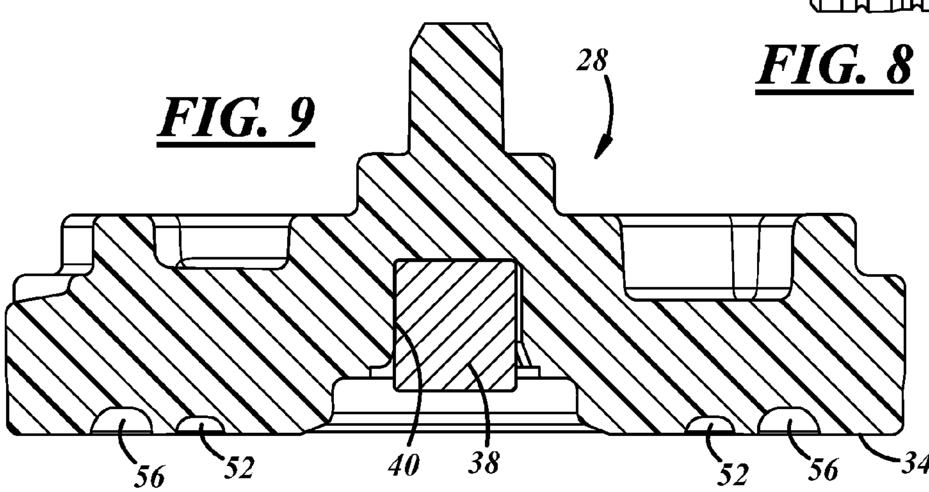

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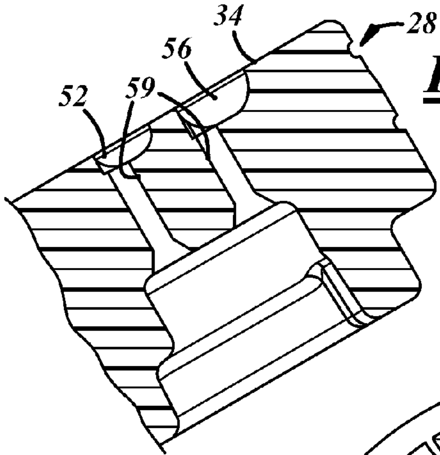

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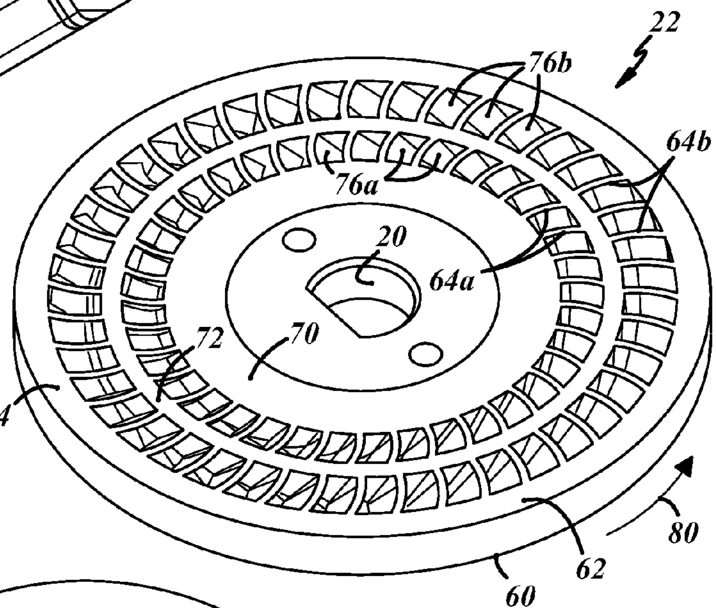

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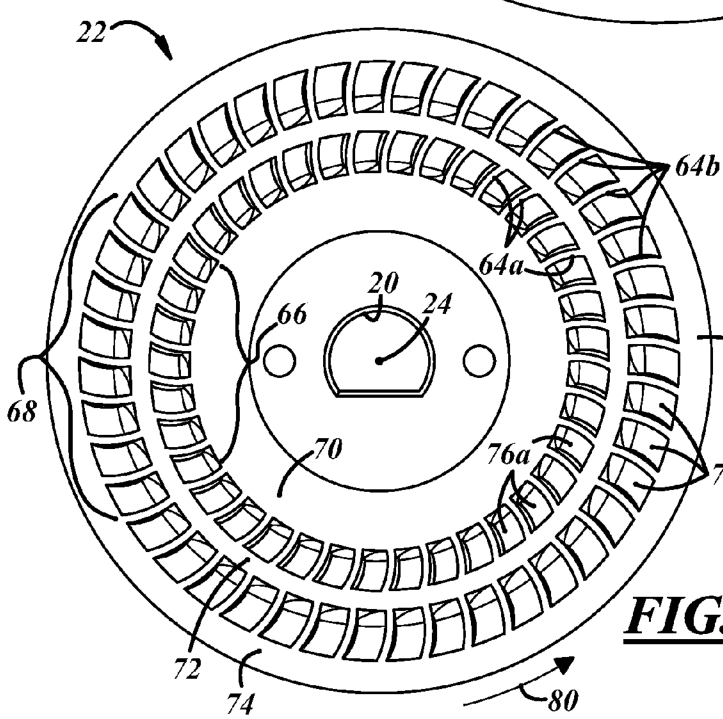

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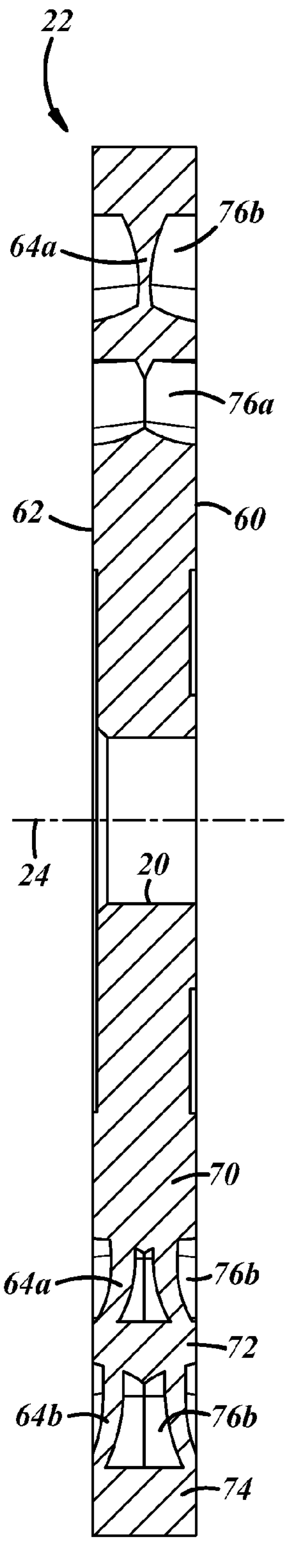

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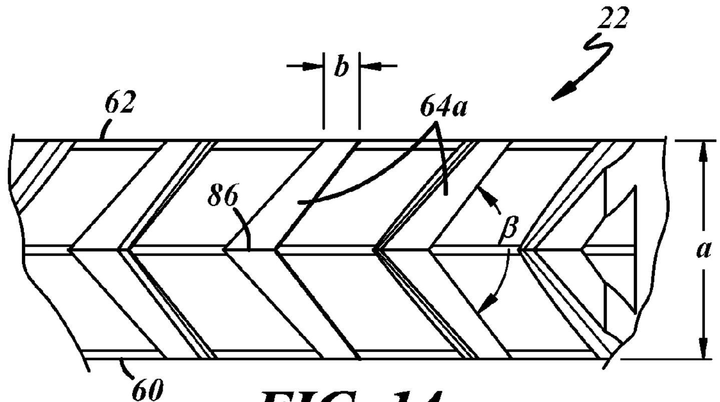

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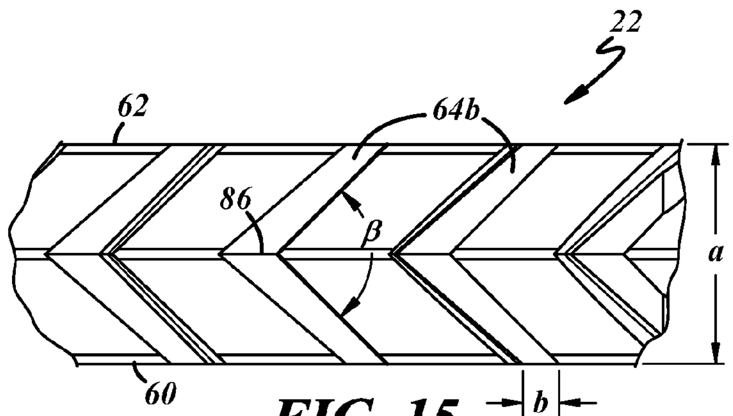

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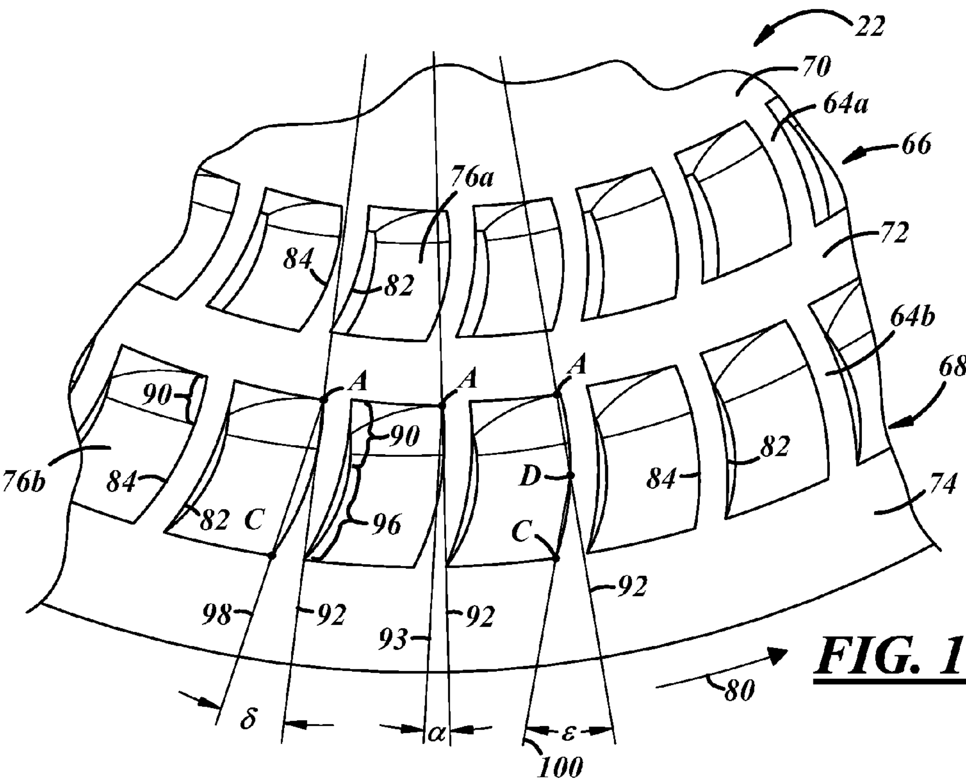


FIG. 16

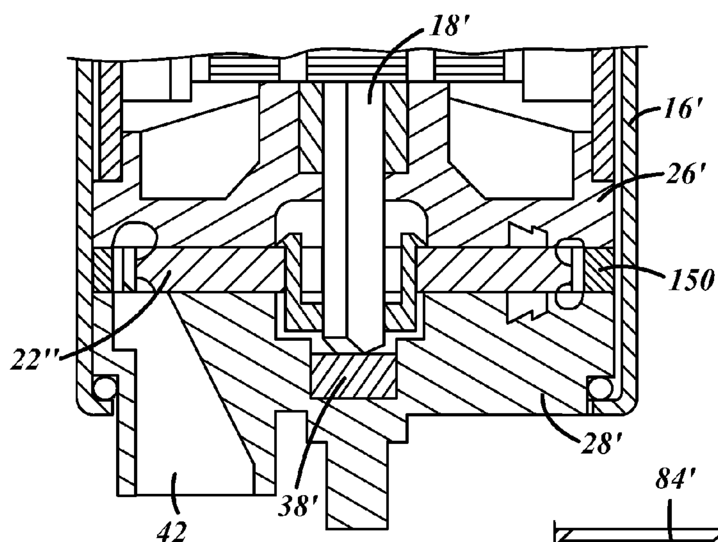
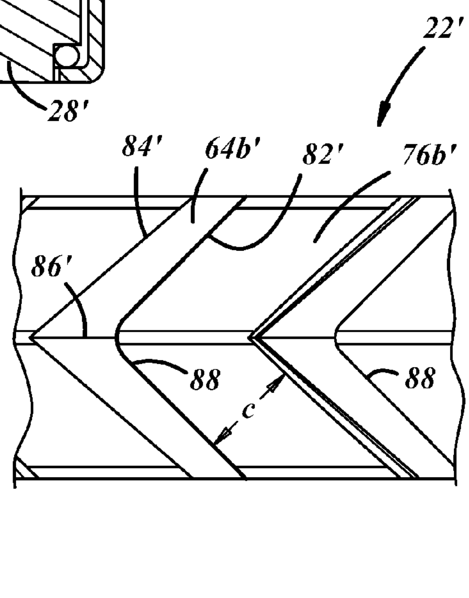


FIG. 19



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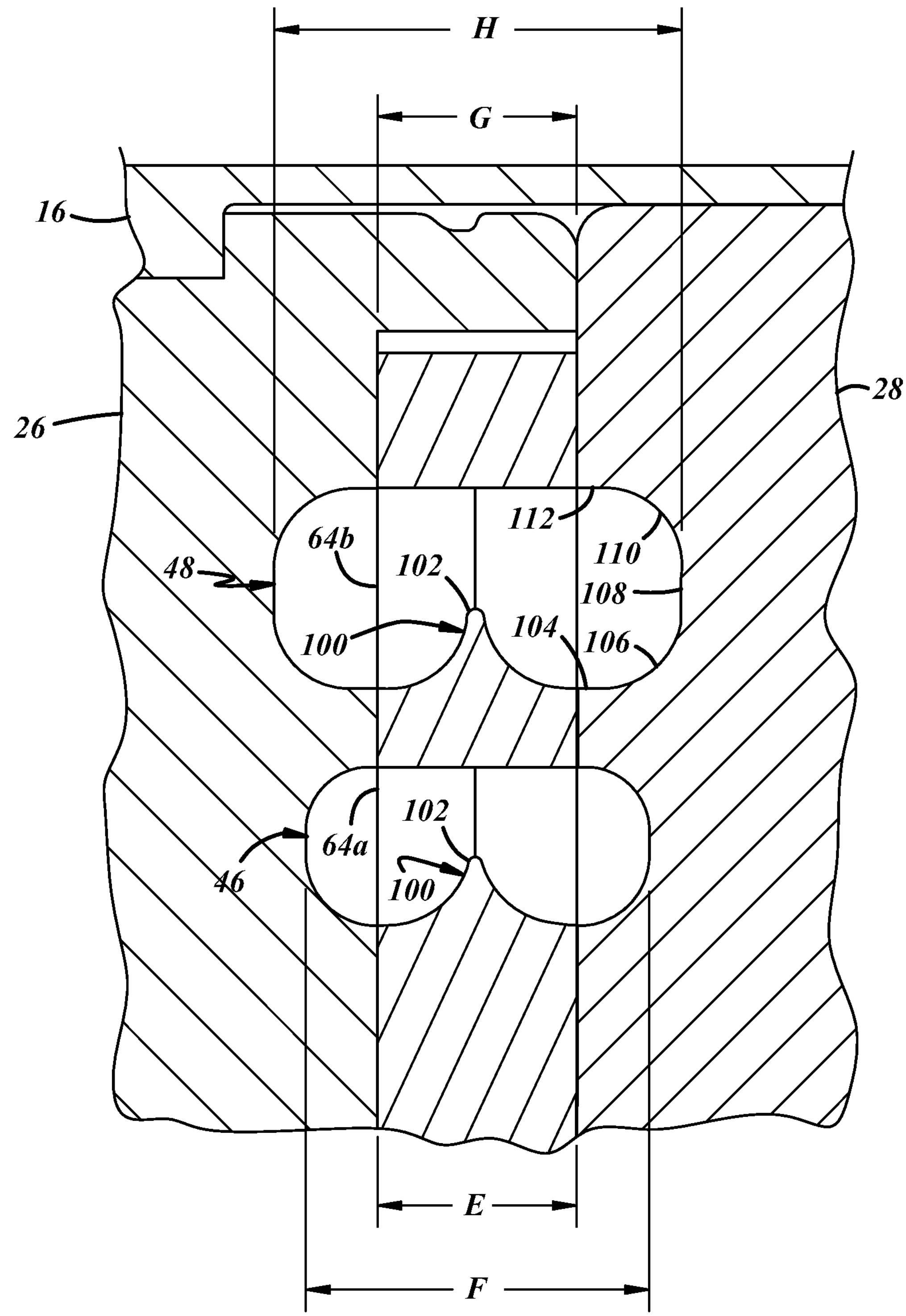
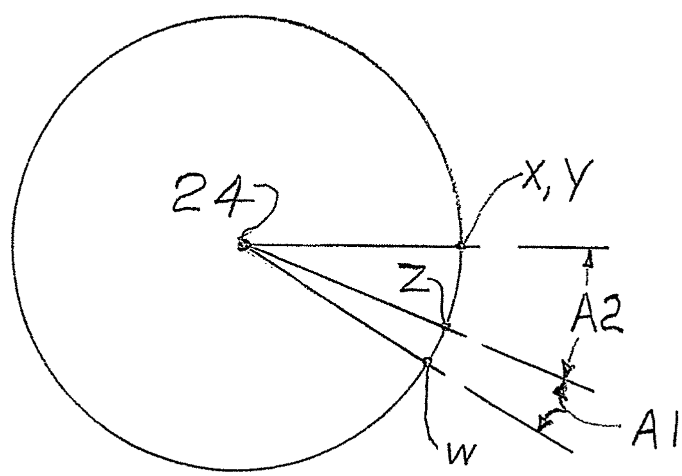


FIG. 18

FIG. 20



IMPELLER AND FLUID PUMP

REFERENCE TO COPENDING APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application Ser. Nos. 61/439,793 filed Feb. 4, 2011 and 61/446,331 filed Feb. 24, 2011, which are incorporated herein by reference in their entirety.

TECHNICAL FIELD

The present disclosure relates generally to fuel pumps and more particularly to a turbine type fuel pump.

BACKGROUND

Electric motor driven pumps may be used to pump various liquids. In some applications, like in automotive vehicles, electric motor driven pumps are used to pump fuel from a fuel tank to a combustion engine. In applications like this, turbine type fuel pumps having an impeller with a plurality of vanes may be used.

SUMMARY

A fluid pump may include an electric motor having an output shaft driven for rotation about an axis and a pump assembly coupled to the output shaft of the motor. The pump assembly has a first cap and a second cap with at least one pumping channel defined between the first cap and the second cap, and an impeller received between the first cap and the second cap. The impeller is driven for rotation by the output shaft of the motor and includes a plurality of vanes in communication with the at least one pumping channel. Each vane has a root segment and a tip segment and a line from a base of the root segment to an outer edge of the tip segment trails a line extending from the axis of rotation to the base of the root segment by an angle of between 0° and 30° relative to the direction of rotation of the impeller.

An impeller for a fluid pump includes a hub having an opening adapted to receive a shaft that drives the impeller for rotation, a mid-hoop spaced radially from the hub and an outer hoop spaced radially from the mid-hoop, and inner and outer arrays of vanes. The inner array of vanes is located radially outwardly of the hub and inwardly of the mid-hoop. The outer array of vanes is located radially outwardly of the mid-hoop. Each vane in the inner array and the outer array has a leading face and a trailing face spaced circumferentially behind the leading face relative to the intended direction of rotation of the impeller. Each vane has a root segment and a tip segment extending generally radially outwardly from the root segment, and each vane is oriented so that a line from a base of the root segment to an outer edge of the tip segment trails a line extending from the axis of rotation to the base of the root segment by an angle of between 0° and 30°, relative to the direction of rotation of the impeller.

A method of making an impeller includes forming an impeller having a plurality of vanes and adapted to be rotated about an axis, forming a body that defines a radially outer sidewall of an impeller cavity in which the impeller rotates, and machining an axial face of the impeller and the body while the impeller is disposed radially inwardly of the sidewall to provide a similar axial thickness of both the sidewall and impeller.

BRIEF DESCRIPTION OF THE DRAWINGS

The following detailed description of exemplary embodiments and best mode will be set forth with reference to the accompanying drawings, in which:

FIG. **1** is a sectional view of an exemplary fluid pump showing portions of an electric motor and pumping assembly of the fluid pump;

FIG. **2** is a sectional view of a pumping assembly of the fluid pump showing upper and lower caps and an impeller;

FIG. **3** is a top view of the upper cap;

FIG. **4** is a side view of the upper cap;

FIG. **5** is a sectional view of the upper cap;

FIG. **6** is a bottom view of the upper cap showing a lower surface of the upper cap;

FIG. **7** is a top view of the lower cap showing an upper surface of the lower cap;

FIG. **8** is a side view of the lower cap;

FIG. **9** is a sectional view of the lower cap;

FIG. **10** is a fragmentary sectional view of a portion of the lower cap showing vent passages formed therein;

FIG. **11** is a perspective view of the impeller;

FIG. **12** is a top view of the impeller;

FIG. **13** is a sectional view of the impeller taken along line **13-13** in FIG. **12**;

FIG. **14** is an enlarged, fragmentary sectional view taken along line **14-14** in FIG. **12**;

FIG. **15** is an enlarged, fragmentary sectional view taken along line **15-15** in FIG. **12**;

FIG. **16** is an enlarged, fragmentary view of a portion of the impeller;

FIG. **17** is an enlarged, fragmentary sectional view of a modified impeller;

FIG. **18** is an enlarged fragmentary sectional view of the impeller assembled in the upper and lower caps;

FIG. **19** is a fragmentary sectional view of an alternate fuel pump including a ring radially surround at least a portion of the impeller; and

FIG. **20** is a schematic of a circumferential offset of the downstream end of the fuel outlet in the upper and lower caps and their circumferential location relative to the upstream end of the fuel inlet in the upper and lower caps.

DETAILED DESCRIPTION OF PRESENTLY PREFERRED EMBODIMENTS

Referring in more detail to the drawings, FIG. **1** illustrates a liquid pump **10** that has a turbine type or impeller pump assembly **12** that may be driven for rotation by an electric motor **14**. The pump **10** can used to pump any suitable liquid including, and for purposes of the rest of this description, automotive fuels. In this example, the pump **10** may be utilized in an automotive fuel system to supply fuel under pressure to the vehicle's engine. The fuel may be of any suitable type, and the pump **10** may be adapted for use in a so-called "flex fuel vehicle" that may use standard gasoline as well as alternative fuels like ethanol based E85 fuel.

The motor **14** and associated components may be of conventional construction and may be enclosed, at least in part, by an outer housing or sleeve **16**. The pump assembly **12** may also be enclosed, at least in part, by the sleeve **16** with an output shaft **18** of the motor **14** received within a central opening **20** of an impeller **22** to rotatably drive the impeller **22** about an axis **24** of rotation.

As shown in FIGS. **1** and **2**, the pump assembly **12** may include a first or lower cap **28** and a second or upper cap **26** held together and generally encircled by the sleeve **16**. An impeller cavity **30** in which the impeller **22** is received, may be defined between a lower surface **32** of an upper cap **26** and an upper surface **34** of a lower cap **28**. The lower surface **32** and upper surface **34** may be generally flat or planar, and may extend perpendicularly to the axis **24** of rotation. The motor output shaft **18** may extend through a central passage **36** in the upper cap **26**, be coupled to and project through the opening **20** in the impeller **22** with an end of the shaft **18** supported by a bearing **38** located in a blind bore **40** in the lower cap **28**.

One or more fuel pumping channels **46**, **48** (FIG. **1**) are defined within the impeller cavity **30**. The pumping channels **46**, **48** may be defined by and between the impeller **22** and the upper and lower caps **26**, **28**. The pumping channels **46**, **48** may communicate with and extend between an inlet passage **42** and an outlet passage **44**, so that fuel enters the pumping channels **46**, **48** from the inlet passage **42** and fuel is discharged from the pumping channels **46**, **48** through the outlet passage **44**. In the implementation shown, two pumping channels are provided, with an inner pumping channel **46** disposed radially inwardly or an outer pumping channel **48**. The lower cap **28** (FIGS. **1**, **2**, **7-9**) may define all or part of the inlet passage **42** through which fuel flows from a fluid reservoir or fuel tank (not shown) into the pumping channels **46**, **48**. The upper cap **26** (FIGS. **1-6**) may define all or part of an outlet passage **44** through which pressurized fuel is discharged from the pumping channels **46**, **48**.

The inner pumping channel **46** may be defined in part by opposed grooves, with one groove **50** (FIGS. **5** and **6**) formed in the lower surface **32** of the upper cap **26** and the other groove **52** (FIGS. **7** and **9**) formed in the upper surface **34** of the lower cap **28**. The outer pumping channel **48** may also be defined in part by opposed grooves, with one groove **54** (FIGS. **5** and **6**) formed in the lower surface **32** of the upper cap **26** and the other groove **56** (FIGS. **7** and **9**) formed in an upper surface **34** of the lower cap **28**. The grooves **50-56** may all be symmetrically shaped and sized, or, they could be non-symmetrically shaped and/or sized. For example, the grooves **50**, **52** defining part of the inner pumping channel **46** could be generally the same in the upper and lower caps **26**, **28**, but different from the grooves **54**, **56** defining part of the outer pumping channel **46**. As shown in FIG. **10**, vent paths **59** may be provided for one or both pumping channels **46**, **48** to permit vapor to escape or be expelled from the channels.

As shown in FIGS. **2** and **7**, the inlet passage **42** may lead to an entrance portion **58** of the pumping channels **46**, **48**, with the entrance portion of outer pumping channel **48** shown. In the entrance portion **58**, the depth of the pumping channel **48** may change from a greater depth adjacent to the inlet passage **42** to a lesser depth downstream thereof. The reduction in flow area downstream of the inlet passage **42** facilitates increasing the pressure and velocity of the fuel as it flows through this region of the pump assembly **12**. In at least some implementations, the entrance portion may be disposed at an angle θ (FIG. **2**) of between about 0° and 30°. In one presently preferred application, angle θ is between about 13° and 14°.

The outer pumping channel **48**, as shown in FIGS. **5**, **6**, **7** and **9**, may have a cross-sectional area that is larger than that of the inner pumping channel **46**. The inner pumping channel **46** may operate at a lower tangential velocity and a higher pressure coefficient than the outer pumping channel **48** (due to the smaller radius and the shorter circumferential length of the inner pumping channel). In order to reduce leakage and/or backflow in the inner channel **46**, as well as to maximize output flow, a smaller cross-sectional area may be used for the inner pumping channel **46** compared to the outer pumping channel **48**.

The pumping channels **46**, **48** may extend circumferentially or for an angular extent of less than 360°, and in certain applications, about 300-350° about the axis of rotation. This provides a circumferential portion of the upper and lower caps **26**, **28** without any grooves, and where there is limited axial clearance between the upper surface **34** of the lower cap **28** and the impeller lower face **60**, and the lower surface **32** of the upper cap **26** and upper face **62** of the impeller **22**. This circumferential portion without grooves may be called a stripper portion or partition **65** and is intended to isolate the lower pressure inlet end of the pumping channels **46**, **48** from the higher pressure outlet end of the pumping channels. Additionally, there may be generally no, or only a limited amount, of cross fluid communication between the inner and outer pumping channels **46**, **48**. Limited cross fluid communication between the pumping channels **46**, **48** may be desirable to provide a lubricant or a fluid bearing between the rotating impeller **22** and the stationary caps **26**, **28**.

As shown in FIG. **2**, in at least one implementation, a radially inward upstream edge of the inlet **42** at the face **34** of the lower body **28** (shown at point X) may be radially aligned with a radially inward upstream edge of the inlet at the face **32** of the upper body **26** (shown at point Y). That is, a line connecting point X and point Y may be parallel to the axis of rotation. Further, the radially inward downstream edge of the outlet **44** at the face **34** of the lower body **28** (shown at point W) may be circumferentially offset from the radially inward downstream edge of the outlet **44** at the face **32** of the upper body **26** (shown at point Z) by an angle A**1** between about 0° and 20°, with a presently preferred offset in one application being about 4°. Further, points X and Y may be circumferentially offset from point Z by an angle A**2** of about 10° to 25°, with a presently preferred offset in one application being about 23°. These angles may be measured between lines that are parallel to the axis of rotation and extend through the noted points.

The pumping channels **46**, **48** may also be defined in part by the impeller **22**. As shown in FIGS. **1** and **11-16**, impeller **22** may be a generally disc-shaped component having a generally planar upper face **62** received adjacent to the lower surface **32** of the upper cap **26**, and a generally planar lower face **60** received adjacent to the upper surface **34** of the lower cap **28**. The impeller **22** may include a plurality of vanes **64*a,b*** each radially spaced from the axis of rotation **24** and aligned within a pumping channel **46** or **48**. In the implementation shown, where inner and outer pumping channels are provided, the impeller includes an inner array **66** of vanes **64*a*** that are rotated through the inner pumping channel **46** and an outer array **68** of vanes **64*b*** that are rotated through the outer pumping channel **48**.

A circular hub **70** of the impeller **22** may be provided radially inwardly of the inner array **66** of vanes and a key hole or non-circular hole **20** may be provided to receive the motor output shaft **18** such that the shaft and impeller co-rotate about axis **24**. A mid-hoop **72** may be defined radially between the inner and outer vane arrays **66**, **68**, and an outer hoop **74** may be provided or formed radially outward of the outer vane array **68**. To prevent or minimize fuel flow between the inner and outer pumping channels **46**, **48** and to prevent or reduce fuel leakage in general, the upper face **62** and lower face **60** of the impeller **22** may be arranged in close proximity to, and perhaps in a fluid sealing relationship with, the lower surface **32** of the upper cap **26** and the upper surface **34** of the lower cap **28**, respectively. Vane pockets **76*a,b*** may be formed between each pair of adjacent vanes **64*a,b*** on the impeller **22**, and between the mid-hoop **72** and outer hoop **74**. In the example shown in the drawings, the vane pockets **76*a,b*** of both the inner and outer vane arrays **66**, **68** are open on both their upper and lower axial faces, such that the vane pockets **76*a,b*** are in fluid communication with the upper and lower grooves **50-56**. Inner and outer vane arrays **66**, **68** respectively propel the fuel through circumferentially extending inner and outer pumping channels **46**, **48** as the impeller **22** is driven for rotation.

With reference now to FIGS. **11-16**, the inner vane array **66** includes numerous vanes **64***a* that each project generally radially outwardly from the inner hub **70** to the mid-hoop **72**. The outer vane array **68** includes numerous vanes **64***b* that each project generally radially outwardly from the mid-hoop **72** to the outer hoop **74**. Thus, the mid-hoop **72** separates the inner vane array **66** from the outer vane array **68**. The vanes **64***a,b* of both the inner and outer vane arrays **66**, **68** and the mid-hoop **72** and outer hoop **74** may extend axially the same distance, generally denoted by dimension "a" on FIGS. **14** and **15**. Each vane **64***a,b* may have a desired circumferential thickness denoted by dimension "b" on FIGS. **14** and **15**. The shape, orientation and spacing between the vanes **64***a* of the inner vane array **66** may be different than for the vanes **64***b* of the outer vane array **68**, or the arrangement of the vanes **64***a*, **64***b* in both vane arrays may be the same. In the example shown in the drawings, the shape and orientation of the vanes **64***a,b* is the same in the inner and outer vane arrays **66**, **68**, although the inner array **66** is smaller radially and circumferentially than the outer array **68** and preferably has fewer vanes than the outer array.

Turning now to FIG. **16**, there is shown an enlarged view of part of the inner and outer vane arrays **66**, **68**. The following description is directed primarily to the outer vane array **68** but applies also to the inner vane array **66**, unless otherwise stated. In the implementation shown, the impeller **22** is rotated counterclockwise, as viewed in FIG. **16** and as indicated by arrow **80**, by the motor to take fuel in through the inlet **42** and discharge fuel under pressure through the outlet **44**. Each vane **64***b* has a leading face **82** and a trailing face **84** that is disposed circumferentially behind the leading face, relative to the direction of rotation. If desired, the shape of the leading and trailing faces **82**, **84** may be the same, or nearly so, so that the vanes **64***b* have a generally uniform circumferential thickness. As shown in FIG. **15**, each vane **64***b* may be generally v-shaped in cross-section with ends adjacent to each axial face **60**, **62** of the impeller **22** leading (i.e. inclined forwardly relative to the direction of rotation) an axial mid-point **86** of the vane. FIG. **14** shows a similar view of some vanes **64***a* from the inner vane array **66**. In this way, the vanes **64***a,b* may be defined as having an upper half that extends axially from the upper face **62** of the impeller **22** to the mid-point **86** and a lower half that extends axially from the mid-point **86** to the lower face **60** of the impeller **22**. The axial midpoint **86** of each vane **64***b* trails the portion of each vane adjacent the upper face **62** of the impeller **22**. And the axial mid-point **86** of each vane **64***b* trails the portion of the vane adjacent the lower face **60** of the impeller **22**. This provides a generally concave vane in the cross-section views of FIGS. **14** and **15**. Preferably, in cross-section, the front face of both the upper and lower halves of the vanes **64***a,b* is also concave, and the rear face of each half is convex.

In FIGS. **14** and **15**, the upper and lower halves of the vanes **64***b* converge at the mid-point **86** and may define a relatively sharp transition and the v-shape as discussed above. The angle β defined between the upper and lower halves in each vane may be between 60° and 130°. A modified impeller **22'** is shown in FIG. **17** wherein the leading face **82'** of each vane **64***b*' has an arcuate or radiused region **88** in the area the axial mid-point **86'** of each vane, providing more of a U-shape in that area rather than a sharp V-shape. The radius may be 90% less than to 50% greater than the minimum spacing in any direction (nominally denoted by dimension "c", which could be at other positions and angles in other designs) between (1) the leading face **82'** of a vane and (2) the trailing face **84'** of the adjacent vane, along the axial length of the vanes. So, by way of a non-limiting example, if the minimum length or distance of the vane pocket **76***b*' is 1 mm, then the radius would be between 0.1 mm and 1.5 mm.

As shown in FIG. **2**, an angle ψ is formed between the entrance portion **58** of a pumping channel **46** or **48** and the lower half of an associated vane **64***a* or **64***b*. Preferably, but not necessarily, the angle ψ is greater than 109° for both pumping channels **46** and **48** and associated vanes **64***a* and **64***b*. In at least some implementations, the angle ψ for the inner pumping channel **46** and inner vanes **64***a* is between 110° and 120°, and may be about 114°. In at least some implementations, the angle ψ for the outer pumping channel **48** and outer vanes **64***b* is between 110° and 125°, and may be about 121-122°.

Referring again to FIG. **16**, each vane **64***b* includes a root segment **90** that extends outwardly from the mid-hoop **72** (the root segment **90** of the vanes **64***a* in the inner array **66** extend outwardly from the hub **70** rather than the mid-hoop **72**). The root segment **90** may be linear, or nearly so, if desired, and may be between about 10% to 50% of the radial length of the vane **64***b*. The root segment **90** may extend at an angle α to a radial line **92** extending from the axis of rotation **24** through a point A on the trailing face **84** of the vane at the radially inward end of the root segment **90**. The angle α may be between about −20° to 10° and is shown between the radial line **92** and a line **93** extending along the root segment **90** on the trailing face **84** of the vane **64***b*. An angle less than zero indicates that the root segment **90** (and hence, line **93**) is inclined rearwardly compared to the radial line **92** and relative to the direction of rotation **80**. An angle greater than zero indicates that the root segment **90** is inclined forwardly compared to the radial line **92** and relative to the direction of rotation. In one presently preferred embodiment, α is about −3° which means the root segment **90** is retarded or angled rearwardly of the radial line **92**.

Each vane **64***b* also includes a tip segment **96** that extends from the radially outer end of the root segment **90** to the outer hoop **74** (the tip segment **96** of the vanes **64***a* in the inner array **66** extend to the mid-hoop **72** rather than the outer hoop **74**). As shown in the drawings, tip segment **96** is slightly curved such that it is convex (when viewed in a direction parallel to the axis of rotation **24**) with respect to the direction of rotation **80**. Thus, the radially outermost portion of the tip segment **96** trails the root segment **90** relative to the direction of rotation **80**. An angle δ is formed between the radial line **92** and a line **98** extending from a point A at the mid-hoop **72** on the trailing face **84** of the vane (i.e. the base of the root segment **90**) to a point C at the outer hoop **74** on the trailing face **84** of the vane (i.e. the end of the tip segment **96**). The angle δ may be between about 0° and −30°, where zero degrees coincides with the radial line **92** and angles of less than zero degrees indicate that the line **98** trails the radial line **92** relative to the direction of rotation **80**. In one presently preferred embodiment, angle δ is about −12° which means the vane **64***b* is retarded or angled rearwardly of the radial line **92**. The orientation of the vane **64***b* may also be described with referent to a line **100** that extends from point D at the radial mid-point **86** of the vane **64***b* to point C. Line **100** may form an angle ϵ with the radial line **92**, and this angle ϵ may range between about 5° and 45°. If desired, tip segment **96** may have a generally uniform curvature that may be defined by an imaginary radius in the range of between 2 mm to 30 mm. In at least one implementation, no portion of the vane **64***b* extends forwardly of or leads the radial line **92**, relative to the direction of rotation of the impeller. And the tip segment **96** of the vane may extend more rearwardly of the radial line **92** than the root segment **90**.

As shown in FIGS. **16** and **18**, a rib or partition **100** extends circumferentially between adjacent vanes with a tip **102** axially centered between the faces **60**, **62** of the impeller. The rib **100** may extend radially outwardly, and may extend between about ¼ and ½ of the radial extent of its associated vanes. As shown in FIG. **18**, preferably but not necessarily, each groove in cross-section has a straight section **104**, a first curved section **106**, a bottom straight section **108**, a second curved section **110**, and a straight section **112**. Each straight section **104**, **112** may be perpendicular to the adjacent face of the impeller **22** and the straight section **108** may be parallel to an adjacent face of the impeller. The curved sections **106** and **110** may have radii of the same length with different centers and blend smoothly into the adjoining straight sections at both ends of each curved section.

As shown in FIG. **18**, the axial extent E of each inner vane **64***a* to the axial extent F of its pumping channel **46** may (but is not required to) have the relationship of $F/E<0.6$. The axial extent G of each outer vane **64***b* to the axial extent H of its pumping channel **48** may have the relationship of $H/G>0.76$. Preferably, but not necessarily, in a plane containing the impeller axis **24**, the ratio of the area A_2 of a pump channel **46** or **48** including the area of an associated vane **64***a* or **64***b* to the area A_1 of its associated vane **64***a* or **64***b* excluding the area of its rib **100** is $A_2/A_1<1.0$. In at least some implementations, for the inner channel **46** and inner vanes **64***a*, $A_2/A_1 \leq 0.7$, and for the outer channel **48** and outer vanes **64***b*, $A_2/A_1 \leq 0.9$.

In operation, rotation of impeller **22** causes fuel to flow into the pump assembly **12** via the fuel inlet passage **42**, which communicates with the inner and outer pumping channels **46**, **48**. The rotating impeller **22** moves fuel from the inlet **42** toward the outlet **44** of the fuel pumping channels and increases the pressure of the fuel along the way. Once the fuel reaches the annular end of the pumping channels **46**, **48**, the now pressurized fuel exits pump assembly **12** through the fuel outlet passage **44**. Because the fluid pressure increases between the inlet and outlet of the pump assembly **12**, orienting the vanes **64***a,b* so that they are rearwardly inclined (that is, they trail the radial line **92** as discussed above) improves circulation of the fluid within the vane pockets **76***a,b* and pumping channels **46**, **48** because the higher pressure upstream of a vane pocket **76***a,b* helps to move fluid radially outwardly since the fluid pressure at the tip segment **96** may be slightly lower than the fluid pressure at the root segment **90** when the tip segment **96** trails the root segment **90**. If the tip segment **96** were advanced forward of the root segment **90**, then the pressure at the radially outwardly located tip segment would be greater than the pressure at the root segment and this tends to inhibit circulation and outward flow of the fluid in at least some implementations.

Further, orienting the root segment **90** at a different angle than the tip segment **96**, and generally at a lesser trailing angle than the tip segment, helps to move fluid in the lower pressure inlet region of the pumping channels **46**, **48**. It is believed that the more radially oriented root segments **90** tend to lift the fluid axially and improve flow and circulation of the fluid in the inlet regions. This tends to improve performance of the pump assembly **12** in situations where the fluid is hot and poor or turbulent flow might lead to vapor formation or other inefficient conditions.

Therefore, in one sense, it can be considered that the root segment is designed for improved low pressure and hot fluid performance and the tip segment is designed for improved higher pressure performance. With these performance characteristics, the impeller and pump assembly are well-suited for use in various fluids, including volatile fuels such as unleaded gasolines and ethanol based fuels such as are currently used in automotive vehicles.

As shown in FIGS. **1-6**, one or both of the upper and lower cap may have an integral radially outwardly located and circumferentially and axially extending flange **35** (shown on upper cap **26** in this implementation) defining a side wall or boundary of the impeller cavity that may be formed in one-piece with the cap. Alternatively, a separate ring **150** may be disposed between the upper and lower caps **26'**, **28'** and surrounding the impeller **22"**, as shown in FIG. **19** (FIG. **19** shows a different pump with a different style impeller than the other embodiments discussed above. The impeller of FIG. **19** has only one array of vanes although other vane arrays may be provided. FIG. **19** is provided mainly for its depiction of the ring **150**). With either the separate ring **150** or the integral flange **35**, the impeller **22**, **22'**, **22"** may be machined while in position relative to the ring or flange so that a face of the impeller and the ring or flange are machined at the same time. Representative ways this may be accomplished include inserting the impeller into the ring and machining them together as a set (perhaps with a predetermined thickness differential provided for in a jig or die in which the parts are received for machining), or placing an impeller and ring set into separate portions of a jig or die and machining them generally at the same time though not assembled together. Of course, multiple sets of impellers and guides could be machined at one time, preferably with pairs of impellers and rings maintained together through whatever further processing and assembly steps may occur.

When machined at the same time, the axial thicknesses of these components can be carefully controlled and tolerances or variations from part-to-part in both components can be reduced or eliminated to provide an end product with more tightly controlled tolerances. In at least some implementations, the difference in axial thickness between the impeller and either the ring or flange is about 10 microns or less. The close tolerances and reduced variation from pump-to-pump in a product run help to control the volume of the pumping channels in relation to the axial thickness of the impeller, and maintain a desired clearance between the impeller faces and the adjacent surfaces of the upper and lower caps. This can help improve the consistency between pumps and maintain a desired performance or efficiency across a production run or runs of fluid pumps.

The foregoing description is of preferred exemplary embodiments of the fluid pump; the inventions discussed herein are not limited to the specific embodiments shown. Various changes and modifications will become apparent to those skilled in the art and all such changes and modifications are intended to be within the scope and spirit of the present invention as defined in the following claims. For example, while the drawings show a dual channel, single stage fluid pump, the impeller and other components may be utilized in other pump arrangements, including single channel or more than two channel arrangements, as well as multiple stage pumps. Also, where the vanes **64***a,b* have a generally uniform circumferential thickness along their radial extents, the angles discussed with regard to lines drawn relative to the trailing face of the vanes could also be discussed and applied with regard to lines drawn to the leading face of the vanes.

While the forms of the invention herein disclosed constitute presently preferred embodiments, many others are possible. It is not intended herein to mention all the possible equivalent forms or ramifications of the invention. It is understood that the terms used herein are merely descriptive, rather than limiting, and that various changes may be made without departing from the spirit or scope of the invention.

The invention claimed is:

1. A fluid pump, comprising:

an electric motor having an output shaft driven for rotation about an axis;

a pump assembly coupled to the output shaft of the motor and having:

a first cap and a second cap with at least one pumping channel defined between the first cap and the second cap, and

an impeller received between the first cap and the second cap, wherein the impeller has a hub and a hoop, is driven for rotation by the output shaft of the motor and the impeller includes a plurality of vanes disposed between the hub and the hoop and in communication with said at least one pumping channel, each vane has a leading face with a root segment and a curved tip segment and the root segment extends between 10% and 50% of the radial length of each vane;

the leading face of each vane is configured so that a line from a base of the root segment to an outer edge of the tip segment trails a line extending from the axis of rotation to the base of the root segment by a first angle of between 0° and −30° relative to the direction of rotation of the impeller;

the leading face of each vane is also configured so that a line extending from the base of the root segment to the outer end of the root segment is inclined relative to a line extending from the axis of rotation to the base of the root segment by between −20° and 10° relative to the direction of rotation of the impeller;

the leading face of each vane is also configured so that a line extending from a radial mid-point of the vane to a radially outer edge of the vane is inclined relative to a line extending from the axis of rotation to the radial mid-point of the vane by between −5° and −45° relative to the direction of rotation of the impeller;

the leading face of each vane is curved from at least the radial mid-point to the tip of such leading face; and

the leading face of each vane is also configured so that the tip segment is inclined rearwardly to a greater extent than the root segment relative to the direction of rotation of the impeller.

2. The fluid pump of claim **1** wherein each vane has an upper portion extending from an upper face of the impeller to an axial mid-point of the vane and a lower portion extending from the axial mid-point of the vane to a lower face of the impeller, and the transition from the upper portion to the lower portion along the leading face of the vane is radiused providing a generally u-shaped leading face of the vane in cross section.

3. The fluid pump of claim **2** wherein each vane also has a trailing face and the radius is between 90% less than to 50% greater than the minimum spacing between the trailing face of a vane and the leading face of an immediately circumferentially adjacent trailing vane, along the axial length of these faces of these adjacent vanes.

4. The fluid pump of claim **1** wherein the first cap includes an inlet passage through which fuel is admitted to the pumping channel and an entrance portion of the pumping channel, and the entrance portion of the pumping channel is disposed at an angle of between 0 and 30 degrees relative to an internal surface of the first cap and facing the impeller.

5. The fluid pump of claim **4** wherein the entrance portion is disposed at angle of between 13 and 14 degrees.

6. The fluid pump of claim **4** wherein the inlet passage is formed in both the first and second caps, and an upstream edge of the inlet passage at a face of the first cap confronting the impeller is aligned with an upstream edge of the inlet passage at a face of the second cap confronting the impeller so that a line through these upstream edges is parallel to the axis of rotation of the impeller.

7. The fluid pump of claim **4** which also includes an outlet passage from which fuel is discharged from the pumping channel, a downstream edge of the outlet passage at a face of the first cap confronting the impeller and a downstream edge of the outlet passage at a face of the second cap confronting the impeller and these downstream edges of the outlet passage are circumferentially offset by an angle between 0 degrees to 20 degrees, where the angle is measured between two lines each extending radially from the axis of rotation of the impeller and through a respective one of these downstream edges.

8. The fluid pump of claim **7** wherein the angle of the circumferential offset is between 3 to 5 degrees.

9. The fluid pump of claim **4** wherein an upstream edge of the inlet passage at a face of the first cap confronting the impeller and an upstream edge of the inlet passage at a face of the second cap confronting the impeller are circumferentially offset from a downstream edge of the outlet passage at a face of the second cap confronting the impeller by an angle with its vertex on the axis of rotation of the impeller by between 10 and 25 degrees.

10. The fluid pump of claim **9** wherein the circumferential offset is between 22 and 24 degrees.

11. The fluid pump of claim **1** wherein the first cap includes an inlet passage through which fuel is admitted to the pumping channel and the inlet passage has an entrance portion directly adjacent to the pumping channel, and an angle greater than 109 degrees is formed between the entrance portion of a pumping channel and a lower half of a vane disposed in the pumping channel.

12. The fluid pump of claim **11** which includes an inner pumping channel and an outer pumping channel, and the impeller includes an inner array of vanes located in the inner pumping channel and an outer array of vanes located in the outer pumping channel, and the angle between the entrance portion of the inner pumping channel and a lower half of a vane in the inner array of vanes is between 110 and 120 degrees.

13. The fluid pump of claim **11** which includes an inner pumping channel and an outer pumping channel, and the impeller includes an inner array of vanes located in the inner pumping channel and an outer array of vanes located in the outer pumping channel, and the angle between the entrance portion of the outer pumping channel and a lower half of a vane in the outer array of vanes is between 110 and 125 degrees.

14. The fluid pump of claim **1** which includes an inner pumping channel and an outer pumping channel, and the impeller includes an inner array of vanes located in the inner pumping channel and an outer array of vanes located in the outer pumping channel, and the ratio of the axial extent of each inner vane to the axial extent of the inner pumping channel is less than 0.6.

15. The fluid pump of claim **1** which includes an inner pumping channel and an outer pumping channel, and the impeller includes an inner array of vanes located in the inner pumping channel and an outer array of vanes located in the outer pumping channel, and the ratio of the axial extent of each outer vane to the axial extent of the outer pumping channel is greater than 0.76.

16. An impeller for a fluid pump, comprising:

a hub having an opening adapted to receive a shaft that drives the impeller for rotation, a mid-hoop spaced radially from the hub and an outer hoop spaced radially from the mid-hoop;

an inner array of vanes located radially outwardly of the hub and inwardly of the mid-hoop; and

an outer array of vanes located between the mid-hoop and the outer hoop, both the inner array of vanes and the outer array of vanes configured to communicate with a single common fluid inlet and a single common fluid outlet,

each vane in the inner array and the outer array has a leading face and a trailing face spaced circumferentially behind the leading face relative to the intended direction of rotation of the impeller, each vane has a root segment and a curved tip segment extending generally radially outwardly from the root segment, and the root segment extends between 10% and 50% of the radial length of each vane;

the leading face of each vane is configured so that a line from a base of the root segment to an outer edge of the tip segment trails a line extending from the axis of rotation to the base of the root segment by a first angle of between 0° and −30°, relative to the direction of rotation of the impeller;

the leading face of each vane is also configured so that a line extending from a radial mid-point of the vane to a radially outer edge of the vane is inclined relative to a line extending from the axis of rotation to the radial mid-point of the vane by a second angle of between −5° and −45° relative to the direction of rotation of the impeller; and

the leading face of each vane is also configured so that a line extending from the base of the root segment to the outer end of the root segment is inclined relative to a line extending from the axis of rotation to the base of the root segment by a third angle of between −20° and 10° relative to the direction of rotation of the impeller;

the leading face of each vane is curved from at least the radial mid-point to the tip of such leading face; and

the leading face of each vane is also configured so that the tip segment is inclined rearwardly to a greater extent than the root segment relative to the direction of intended rotation of the impeller.

17. The impeller of claim **16** wherein each vane has an upper portion extending from an upper face of the impeller to an axial mid-point of the vane and a lower portion extending from the axial mid-point of the vane to a lower face of the impeller, and the transition from the upper portion to the lower portion along the leading face of the vane is radiused providing a generally u-shaped leading face of the vane in cross section.

18. The impeller of claim **17** wherein the leading face of each vane has a radius between the upper portion and the lower portion and the radius is between 90% less than to 50% greater than the minimum spacing between the trailing face of a vane and the leading face of an immediately circumferentially adjacent trailing vane, along the axial length of these faces of these adjacent vanes.

19. The impeller of claim **16** wherein each vane is generally v-shaped in cross-section with ends adjacent to each axial face of the impeller leading an axial mid-point of each vane relative to the direction of rotation of the impeller.

20. The impeller of claim **16** wherein each vane has an axial midpoint between axially spaced faces of the impeller, an upper half of each vane defined from an upper face of the impeller to the midpoint and a lower half of each vane defined between the lower face of the impeller to the midpoint, and the upper and lower halves of each vane are configured to define an angle between them of 60 to 30 degrees.

21. The impeller of claim **16** wherein the first angle is between −12 and −30 degrees relative to the intended direction of rotation of the impeller.

22. The method of making a fluid pump impeller, comprising:

forming an impeller having a plurality of vanes in axially opposed faces and adapted to be rotated about an axis,

forming a body that defines a radially outer sidewall of an impeller cavity in which the impeller rotates, the body having at least one generally axial face;

positioning the impeller and the body so that one axial face of each may be machined at substantially the same time; and

machining one axial face of the impeller and the body while so positioned and at substantially the same time to provide a similar axial thickness of the outer sidewall of the body and of the impeller.

23. The method of claim **22** wherein the resulting difference in the axial thickness between the impeller and the sidewall is 10 microns or less.

24. The method of claim **22** wherein the impeller is received between first and second caps in use and the body is an annular ring that is formed separately from the first and second caps.

25. The method of claim **22** wherein the impeller is received between first and second caps in use and the body is an annular flange that is formed in one piece with one of the first or second caps.

26. The method of claim **22** further comprising positioning the impeller radially inwardly of the outer sidewall at least while machining the one axial face of the impeller and the outer sidewall of the body to provide the similar axial thickness of both the outer sidewall and the impeller.

27. The method of claim **26** wherein the resulting difference in the axial thickness between the impeller and the sidewall is 10 microns or less.

28. The method of claim **26** wherein the impeller is received between first and second caps in use and the body is an annular ring that is formed separately from the first and second caps.

29. The method of claim **26** wherein the impeller is received between first and second caps in use and the body is an annular flange that is formed in one piece with one of the first or second caps.

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